BIOLOGICAL EVALUATION R2-05-08

EVALUATION OF WHITE PINE BLISTER RUST AND MOUNTAIN PINE BEETLE ON LIMBER PINE IN THE BIGHORN NATIONAL FOREST

February 2005

PREPARED BY: James T. Blodgett

James T. Blodgett
Plant Pathologist
Rapid City Service Center

PREPARED BY: Willis C. Schaupp, Jr.

Willis C. Schaupp, Jr.
Entomologist
Rapid City Service Center

PREPARED BY: Daniel F. Long

Daniel F. Long
Biological Technician
Rapid City Service Center

PREPARED BY: Frank Cross

Frank Cross
Group Leader
R2, Forest Health Management

Renewable Resources
USDA Forest Service
Rocky Mountain Region
740 Simms Street
Golden, CO 80401

ACKNOWLEDGMENTS

Many thanks to Denise Hardesty, Kort Herman, Jack Lee, and Tracy Dahl for their field assistance, and to Denise Hardesty for data entry assistance. We also thank Chris Thomas and the staff at the Burgess Visitor Center of the Bighorn National Forest.

EVALUATION OF WHITE PINE BLISTER RUST AND MOUNTAIN PINE BEETLE ON LIMBER PINE IN THE BIGHORN NATIONAL FOREST

By Blodgett, J. T., Schaupp, W. C. Jr., and Long, D. F.

ABSTRACT

To determine disease, physical damage, and insect conditions of limber pine in the Bighorn National Forest 92 plots were used to survey 16 stands during the summer of 2002. White pine blister rust disease, followed by the mountain pine beetle, were the main disturbance agents observed. White pine blister rust ranged from low to high frequency and severity, with trees in all 16 stands having some infection. The rust infection contributed to an estimated 6% mortality of limber pines. The heavy infections observed on live trees will likely result in additional mortality. The mountain pine beetle was observed in 7 of the 16 stands, with high impact at one location. The impact of these disturbance agents and possible management actions are discussed.

INTRODUCTION

Limber pine. Limber pine (*Pinus flexilis* James) is a main vegetative component of many sites of the Bighorn National Forest in Wyoming, often growing where no other tree species can grow. This species grows from lower to upper elevations, and can grow at higher elevation than other trees in the forest. Limber pine is found in narrow stands along the northeast, north, and west edges of the Bighorn National Forest. On the forest, severe damage of this ecologically important species has been associated with white pine blister rust (C*ronartium ribicola* J. C. Fisch. ex Rabenh.) and mountain pine beetle (*Dendroctonus ponderosae* Hopk.).

White pine blister rust. White pine blister rust was introduced into both eastern and western North America in the early 20th century, and has spread throughout the range of five-needle pines, including limber pine. Native five-needle pines have limited resistance, since they did not evolve with the pathogen. The first report of this fungal pathogen in Wyoming was in 1945 in Yellowstone National Park (Brown and Graham 1969).

The fungus has five spore forms and two different hosts in its life cycle. Two spore forms occur only on pines and three spore forms occur only on currant and gooseberry (*Ribes* spp.). The disease cannot spread from pine to pine, but is transmitted to pine by spores produced on *Ribes* leaves, and is transmitted to *Ribes* by spores produced on pine stems and branches. Therefore, *Ribes* is required for this fungus to complete its life cycle. Spread of the disease from *Ribes* to pines is greatest when late summers and early falls are cool and damp, since these conditions favors infection. In both hosts, infection takes place through stomata of leaves.

Trees of all ages and sizes are vulnerable to the disease. Early symptoms on the pines include yellow speckling of needles where infection occurred. The fungus spreads down the needle, and into twig and branches. This results in red to yellow flagging caused by branch girdling. Branch girdling results as the fungus develops cankers (areas of killed bark) that spread down and around branches. Cankered branches are somewhat swollen with older cankers becoming rough, often exuding resin. Various rodents, including squirrels and porcupines, are attracted to resinous cankers and often eat bark off infected branches. Cankers can persist for several years. In late spring and early summer, orange-yellow powdery masses of spores (blisters) might be produced on infected branches after three or more years. Cankers may progress down branches to the main stem, causing symptoms similar to those on branches, or canker progression might stop. Cankers that grow to the main stem can kill trees. Trees that are heavily infected by the pathogen can be weakened, making them more susceptible to attack by other diseases or bark beetles.

<u>Mountain pine beetle.</u> Mountain pine beetle is a native insect that kills limber, ponderosa (*Pinus ponderosa* Dougl. ex Laws.), lodgepole (*Pinus contorta* Dougl. ex Loud.), and other pines in western North America. It belongs to a group of insects known as “bark beetles” that feed under the bark. Millions of trees may be killed each year by this insect throughout the west. The beetles survive in stressed or weakened trees and are often associated with older trees, Lightning strikes, crown or bole breakage, root diseases, and trees previously attacked by the mountain pine beetle or other bark beetles. When favorable conditions exist, populations can quickly increase, resulting in mortality of healthy pines. Mortality rates are often higher in dense stands of mature trees.

The mountain pine beetle typically completes its development in one year, although two years may be needed at high elevations. Adult beetles emerge from previously infested trees in late July or August and fly to attack live trees. They bore through the bark of these trees and lay eggs in the phloem or inner bark along straight (unbranched), vertical galleries. Eggs hatch in one to two weeks. The larvae feed horizontally, girdling trees, which results in tree mortality. The beetles also transmit a blue stain fungus that contributes to tree mortality. Larvae and sometimes adults overwinter under the bark. In spring and early summer, the larvae pupate and then transform into adults. After a few weeks, mature beetles bore through the bark and fly to new trees. After adult beetle emergence, small round emergence holes can be seen in the bark. The year following attack, needles turn rusty brown and begin to drop from the dead trees. Other symptoms of mountain pine beetle infestation may include pitch tubes on the bole and the presence of reddish boring dust in bark crevices and around the tree base.

Dwarf mistletoe. Dwarf mistletoe (*Arceuthobium cyanocarpum* (A. Nelson ex Rydberg) Coulter & Nelson) is a native, flowering, parasitic plant that depends on limber pine for food and water. The aerial shoots mainly function for reproduction, producing small flowers that are pollinated by both insects and wind. Seeds are dispersed by water pressure in the fruit that can shoot seeds 30 to 40 ft. Combined with wind, seeds may be dispersed a far as 100 ft. Birds rarely disseminate dwarf mistletoe. The seeds are sticky and adhere to foliage of surrounding branches and trees. During rain the seeds become slippery and slide down and adhere to branches where they germinate and infect the host. The roots of the dwarf mistletoe penetrate and grow within the host tree's branches. Dwarf mistletoe seeds from the overstory infect smaller trees.

After a few years, infection causes swelling of branches and stems. Abnormal growth on infected branches results in clustered mass of twigs and foliage called "witches-brooms" or "brooms." Gradually intensifying infection results in growth loss, severely damaged and deformed trees, top kill, and eventual mortality.

Study objectives. Johnson and Long (2001) found 150 acres affected by limber pine decline in the Bighorn National Forest during an aerial survey in 2001. This biological evaluation was conducted to examine the increasing mortality of limber pine in the Bighorn National Forest at the request of the forest staff. A comprehensive survey was implemented by the Rapid City Service Center staff, Forest Health Protection unit, Rocky Mountain Region (Region 2), to determine the disease, damage, and insect problems in limber pine stands in the forest. This study describes the site conditions, tree heath, various mortality agents, and stresses associated with the sampled limber pine stands.

METHODS

Stand locations were systematically selected (site unseen), based on current vegetation and accessibility as determined by geographic information system. The occurrence of diseases, damage, and insects were not factors in selecting survey locations. Locations were widely distributed across the forest to represent as many conditions as possible.

In each stand, circular plots of 1/10, 1/20, or 1/40 acre were established, depending on the number of trees within the plot. An attempt was made to use the same plot size within a given stand. Plot sizes were selected to ensure a minimum of 3 limber pines and a minimum of 6 trees total per plot. The minimum spacing between plots was 132 ft (2 chains). If plot minimum conditions were not met with the 132 ft spacing, one addition chain was added to the distance between plots until minimum plot conditions were met.

Data recorded at each plot included location coordinates, elevation, a general description of topography and stand structure, slope, aspect, and the occurrence and abundance of *Ribes* spp. For all trees greater than 3 inches in diameter at breast height (DBH; 4.5 ft), species and diameters were determined. All standing limber pine (living and dead), greater than 3 inches DBH, within the plots were measured except very old snags. Only living trees greater than 3 inches DBH were measured for all other tree species. Each stem was counted as a tree if it forked below DBH.

Limber pine trees were examined for the presence of major diseases and insects. Observations and measurements of diseases included the number of branch and stem cankers caused by white pine blister rust, the presence of dwarf mistletoe, and the presence of other major diseases. Observations and measurements of insects included the presence of mountain pine beetle (with approximate year of mortality), other bark beetles, and other insects. Bark beetle attack was confirmed by cutting sections of bark from the trunk to reveal galleries and insects. Additional observations and measurements of limber pine included crown health (percentage of the living crown), and the presence of fire or lightning scars, and/or other physical damage.

Stand means are calculated by first averaging each plot and then averaging all plots within a stand (unless otherwise stated).

RESULTS

Surveyed stands. Sixteen limber pine stands (**Fig. 1**) were surveyed in the Bighorn National Forest in Wyoming during the summer of 2002. Six plots were established in 14 of the stands and four plots were established in two stands (stand 2 and 8) for a total of 92 plots in 16 surveyed stands. Plots averaged 16 trees, with a maximum of 39 trees.

Stand condition. Limber pine was the main tree species in fifteen of the sixteen stands sampled, with Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), lodgepole pine (*Pinus contorta* Dougl. ex Loud.), and Rocky Mountain juniper (*Juniperus scopulorum* Sarg.) being other common associated tree species. Rocky Mountain juniper followed by limber pine were the main tree species in stand 5. The mean DBH of limber pine in all stands was 7.8 inches, and the mean DBH of all tree species combined in all stands was also 7.8 inches. Since limber pine is found mainly along the northeast, north, and west edges of the forest, surveys were located in these areas at elevations of 6,916 to 9,293 ft. *Ribes* species were observed in all stands, ranging in incidence from 17 to 100% (**Fig. 2**), and usually at moderate to high abundance. Limber pine mortality was high in several of the stands (**Fig. 3**), with thinning crowns observed in all stands (**Fig. 4**).

White pine blister rust. The predominant disease agent was white pine blister rust (**Fig. 5**). The rust ranged from low to high frequency and severity, with all 16 stands having some observed infection. Twelve of the 16 stands had standard errors of branch canker incidence greater than the overall standard error for the study. This shows there is much within stand variation. Therefore, multiple plots are needed to describe white pine blister rust branch canker incidence within a stand. Limber pine crown health was well correlated with both white pine blister rust branch ($P < 0.001$) and stem ($P < 0.001$) canker incidence and severity. The rust infection contributed to an estimated 6% mortality of limber pines. This mortality occurred approximately within the past 5 years. The heavy infections observed on live trees will likely result in additional mortality. These values are likely conservative, because branches and stems without obvious rust cankers were classified as uninfected. Yellow speckling of needles and red to yellow flagging symptoms were not counted as infection, because those symptoms might have other causes.

Mountain pine beetle. Mountain pine beetle was also associated with limber pine mortality (**Fig. 6**). The beetle was observed in 7 of the 16 stands, with high mortality in stand 4). Stands with eastern aspects had higher pine beetle incidence (P = 0.004). Current year mountain pine beetle attacks accounted for 70% of the total trees attacked by mountain pine beetle, indicating that beetle losses are increasing. Mountain pine beetle attacks appeared to be focused on larger trees. In stands where the beetle was observed the average diameter of attacked trees was 11.6 inches ± 0.5 standard error (SE) and the average diameter of non-attacked trees was 8.1 inches ± 0.2 SE. Mountain pine beetle incidence was positively correlated with white pine blister rust branch canker severity (P = 0.004) and stem canker incidence (P = 0.001). Mountain pine beetle infested trees also had higher incidences of branch cankers (P = 0.038) and stem cankers (P < 0.001) compared with noninfested trees (64% and 42% verses 49% and 18%, respectively).

Dwarf mistletoe. Dwarf mistletoe was observed only in stand 15. Severe limber pine mortality caused by dwarf mistletoe occurred in only one of the plots. Dwarf mistletoe occurs in other limber pine stands of the Bighorn National Forest that were not sampled during the summer of 2002.

Other observations. Losses due to fire were observed in stands 1 and 3 with incidences of mortality at 1% and 11%, respectively. Other damage of limber pine includes: the red turpentine beetle (*Dendroctonus valens* LeConte), *Ips* spp., and other insects; wind; and lightning. However, incidence were low, and these were not associated with significant mortality.

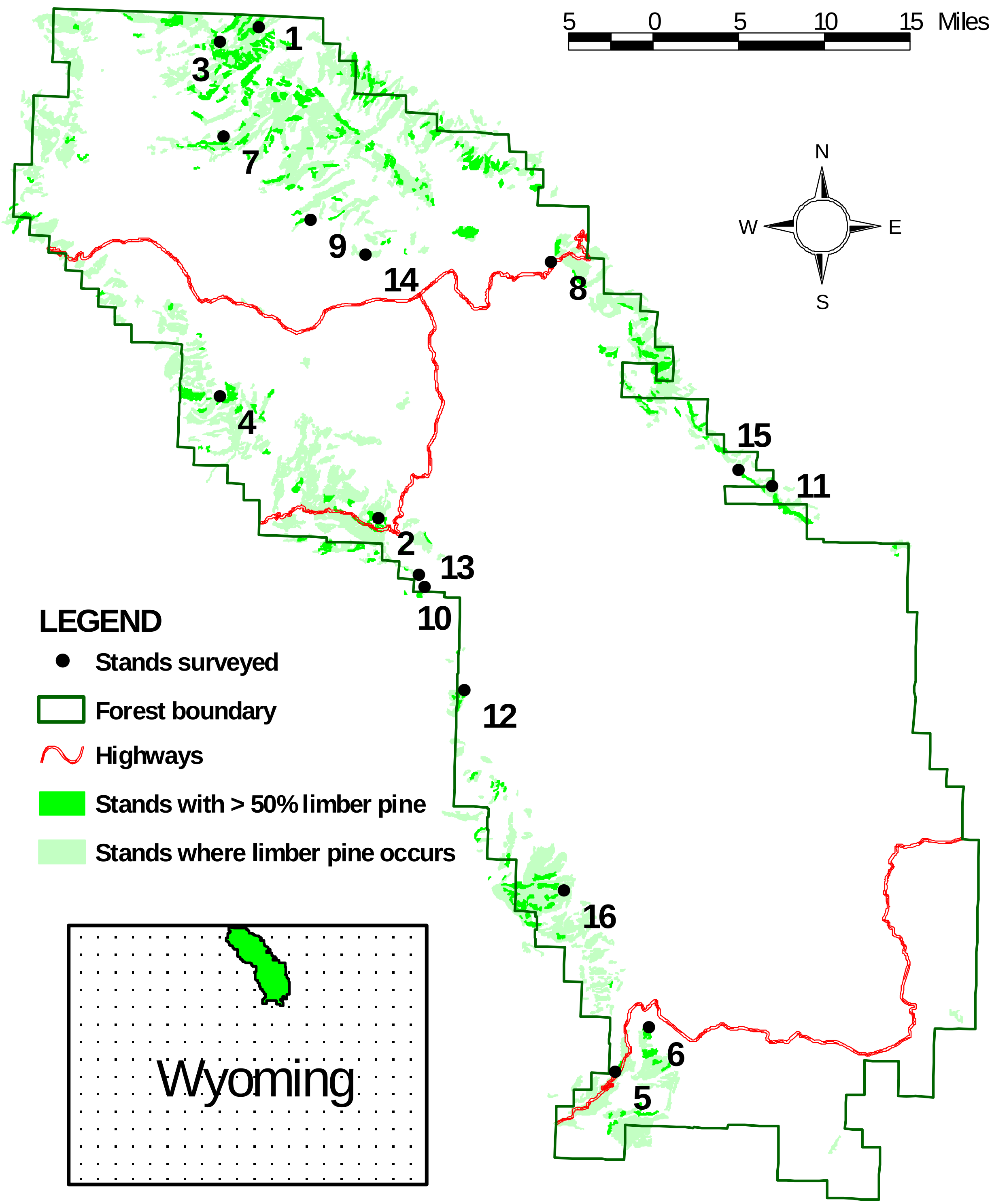

Figure 1. Location of surveyed stands and the distribution of limber pine in the Bighorn National Forest in Wyoming. Numbers identify stands surveyed in 2002.

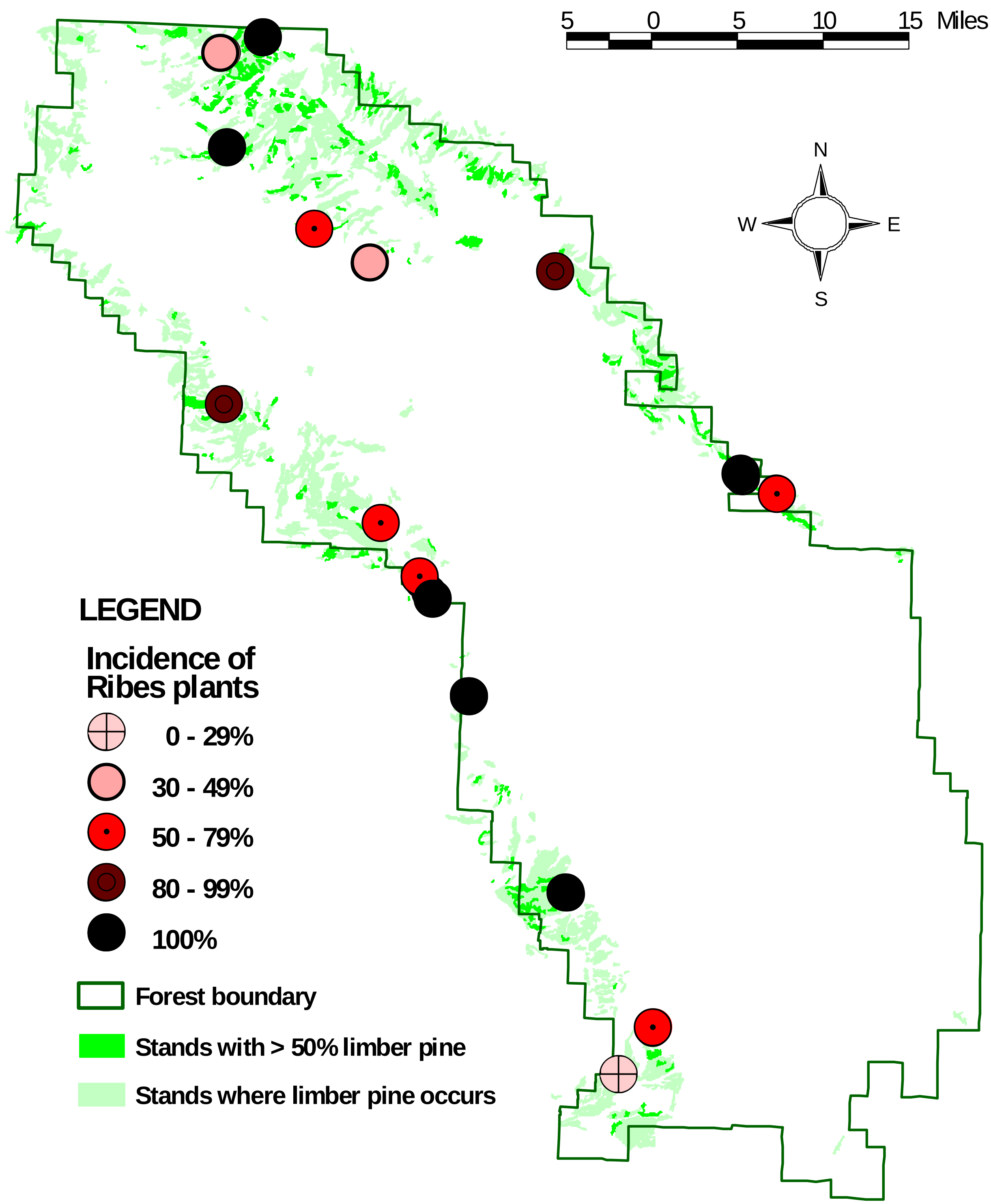

Figure 2. *Ribes* plant incidence in surveyed stands of the Bighorn National Forest in Wyoming during the summer of 2002. Symbols represent the mean percentage of plots in which *Ribes* species were present by stand.

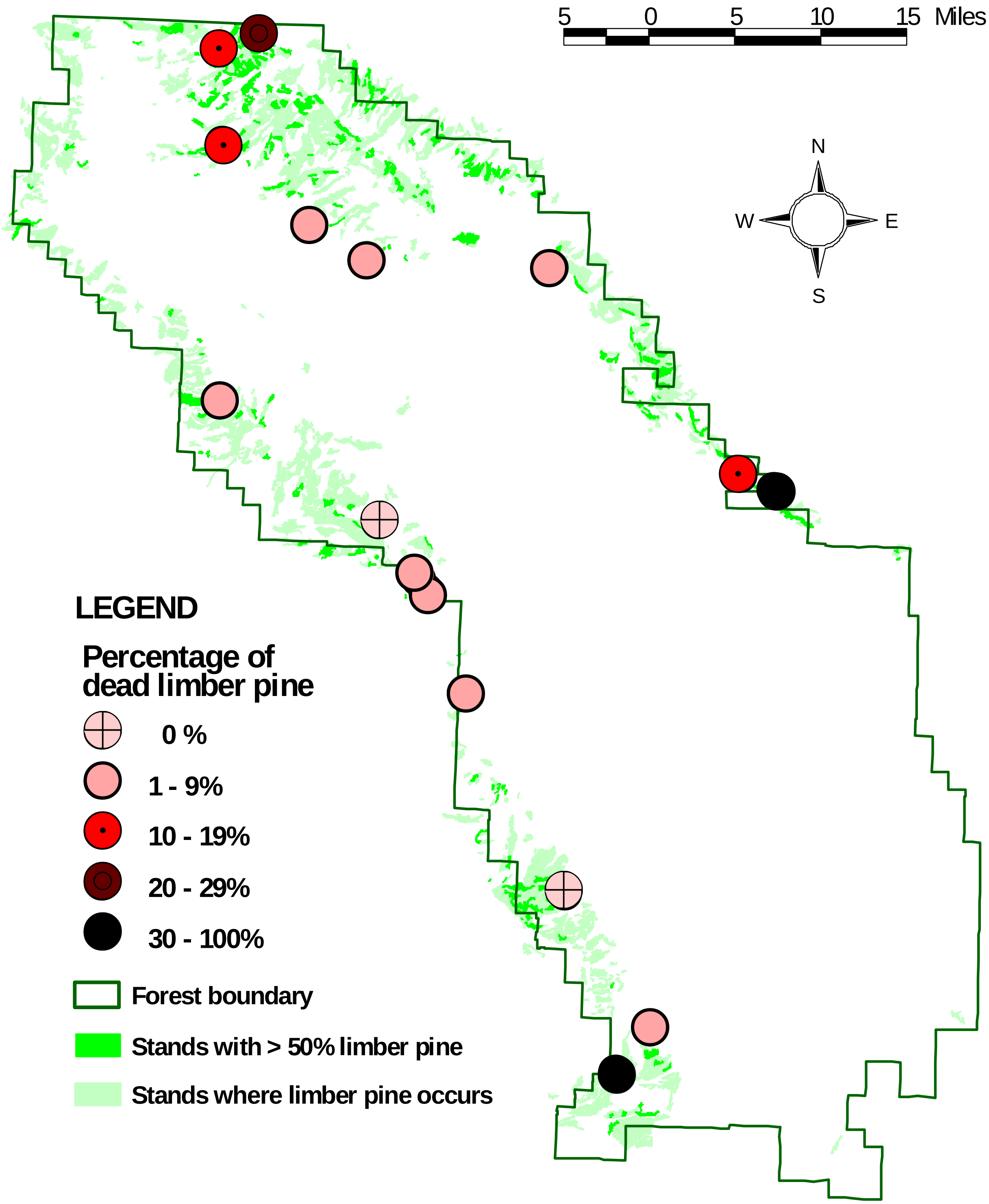

Figure 3. Percentage of recent limber pine mortality in surveyed stands of the Bighorn National Forest in Wyoming during the summer of 2002. Symbols represent the mean percentage of limber pine trees by stand.

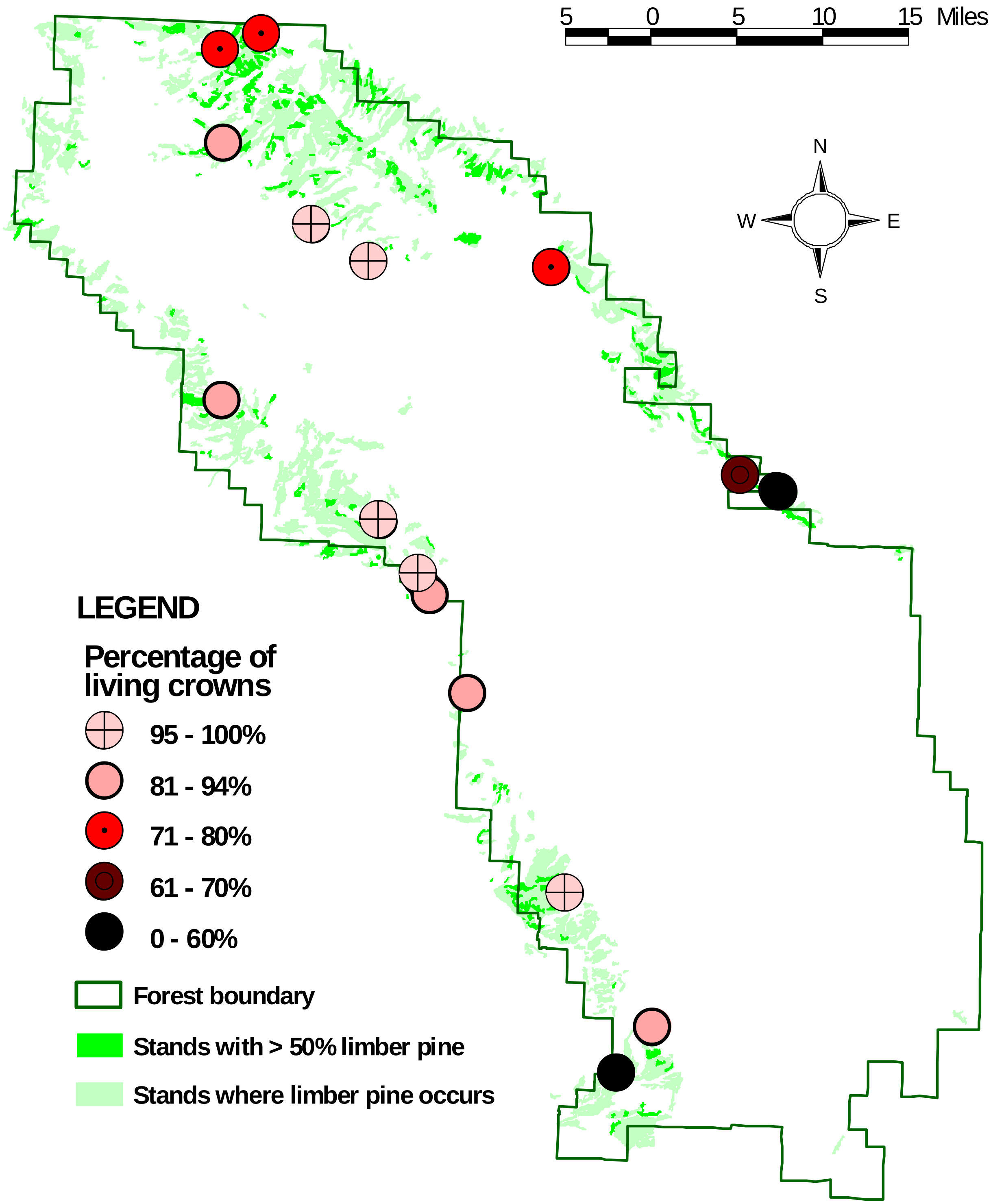

Figure 4. Limber pine crown health expressed as percentage of living crowns in surveyed stands of the Bighorn National Forest in Wyoming during the summer of 2002. Symbols represent the mean live crown percentage for the limber pine trees by stand.

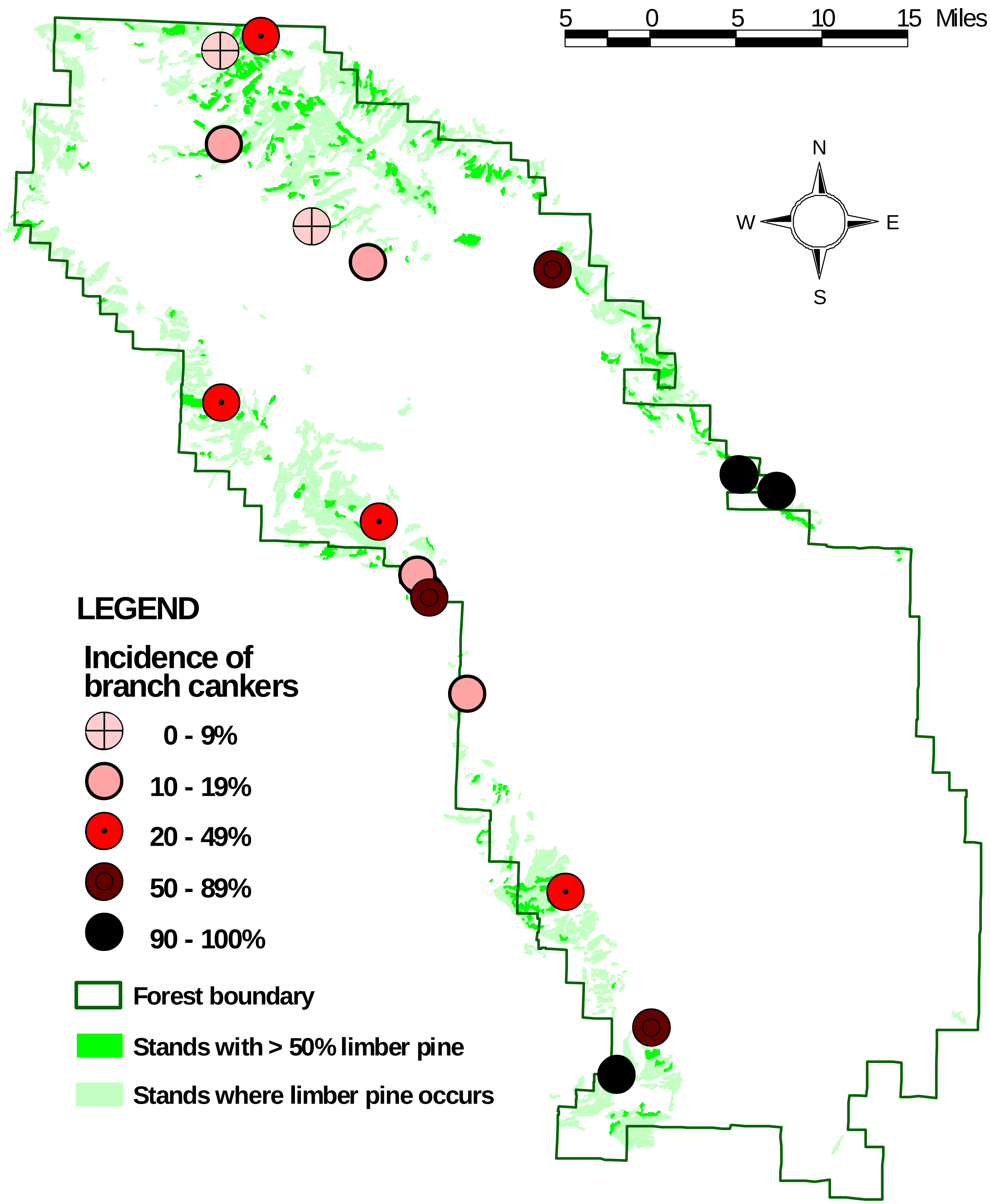

Figure 5. White pine blister rust branch canker incidence in surveyed stands of the Bighorn National Forest in Wyoming during the summer of 2002. Symbols represent the mean incidence for the limber pine trees by stand.

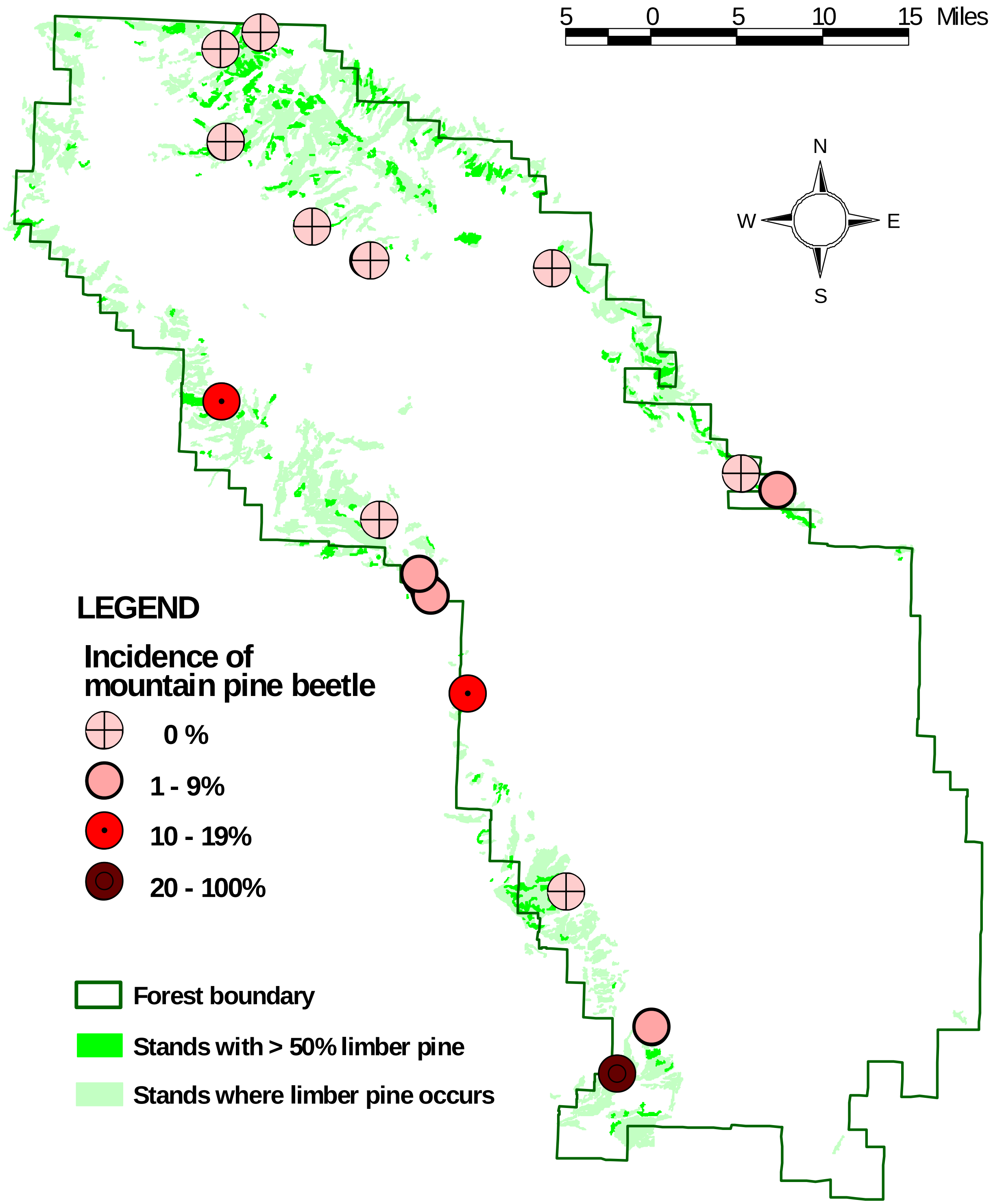

Figure 6. Mountain pine beetle incidence in surveyed stands of the Bighorn National Forest in Wyoming during the summer of 2002. Symbols represent the mean incidence of the limber pine trees by stand.

DISCUSSION

The strong correlation between limber pine crown health and white pine blister rust branch and stem canker incidence and severity, suggests that much of the observed crown deterioration in the Bighorn National Forest is due to white pine blister rust. Significant additional disease associated losses of limber pine should be expected in the Bighorn National Forest. This is based on the high limber pine mortality already present in several stands, and the thinning and rust infected crowns in all stands.

There is a strong correlation between mountain pine beetle incidence and both branch canker severity and stem canker incidence of the rust. This indicates a possible additive effect of the disease and insect. It is probable that white pine blister rust is weakening trees making the trees more susceptible to mountain pine beetle attack. Another possibility is that mountain pine beetle preferentially attack white pine blister rust infected trees. This association between white pine blister rust infection and mountain pine beetle attack might overwhelm the trees defenses, resulting in the observed mortality. Schwandt and Kegley (2004) found that mountain pine beetles may prefer trees infected with rust at low beetle populations, but beetles appeared to prefer trees with little or no rust at higher beetle populations.

Management recommendations are presented that should reduce the rate of loss of limber pine. However, some limber pine mortality from blister rust should be expected even if the recommended management strategies are followed, due to the limited resistance of limber pine to this exotic pathogen.

<u>Limber pine.</u> This species grows from lower to upper elevations in the forest. Many organisms depend on these trees for food and shelter. Limber pine is one of the few tree species able to survive on exposed, high elevation sites. Since limber pine is a main vegetative component on harsh sites in the Bighorn National Forest, mortality due to white pine blister rust (an invasive) and mountain pine beetle might substantially alter the ecosystem. Some of the harsher sites may become devoid of trees for the foreseeable future. Less harsh sites might convert to other tree species. These vegetation changes represent significant effects on both plant and associated animal diversity. Snow retention, stream flow, and water tables may also be affected by the reduction or loss of limber pine.

Management strategies for white pine blister rust. Although limited because of the harshness of the sites, there are effective forest management strategies for controlling this rust.

The best alternative for managing white pine blister rust in the Bighorn National Forest is to utilize disease resistance. One approach would be to identify and collect seed from limber pine that have demonstrated resistance to the rust. This would allow for the selection and development of blister rust resistant limber pine for planting in the future. Resistant varieties of five-needle pines have been developed, but there are no commercially available limber pine resistant to the rust. The development of blister rust-resistant limber pines is likely possible, given that natural resistance to the rust occurs in other native five-needle pines.

A complimentary, and potentially less elaborate approach to improving disease resistance would be to identify and protect expected resistant trees in the field. The objective being to promote natural regeneration with resistant seedlings from locally adapted trees.

Protecting the high value rust resistant limber pine from mountain pine beetle attack can be achieved by applying an appropriate, registered insecticide prior to beetle attack. This is effective, but costly. Carbaryl is a registered insecticide that has been effective in preventing infestation by the beetle on other tree species. Recent trials using the antiaggregant pheromone verbenone (Kegley and Gibson 2004) have been successful in white bark pine, and would likely protect individual limber pine.

There are other forest health management strategies that have been shown to be effective in controlling white pine blister rust. These strategies were developed several years ago for eastern white pine in the Northeast and Lake States (Van Arsdel 1961). Testing and method development is needed for the following actions before they are used operationally to control rust of limber pine in the Rocky Mountain Region. However, some of these actions can be applied with little added cost and they may have a positive effect.

- *Pruning blister rust cankered branches to remove the disease.* Trees with blister rust cankers on the main stem (trunk) or with cankered branches within 4 inches of the main stem cannot be saved. Branches with cankers beyond 4 inches should be removed, no matter where they occur in tree crowns. This prevents cankers from reaching the main stem and killing trees. Pruning cuts should be made immediately outside the branch collar.

- *Basal pruning to reduce tree vulnerability by removing the site of infection (needles).* The fungus requires high moisture for infections, which occur more frequently near the ground. Research with eastern white pine in the Lake States showed that most infections occur within 9 ft of the ground. At least 2/3 of the tree height should remain in live branches. For best control, pruning should begin when trees are young. Since branch cankers frequently occur high in the crowns of limber pine, pruning to reduce vulnerability might not be effective for this host. However, it is possible that basal pruning might deter attack by mountain pine beetle.

- *Selecting sites with good airflow can reduce moist conditions favorable for infection.* The worst thing to do would be to establish pines in small openings, at the bases of slopes, or in low areas. Small openings are openings with diameters less than the height of surrounding trees. These openings and areas can collect cool air, and may favor dew formation that favors rust infection. Site selection is only an option when planting. If resistant or potential resistant limber pine become available, this might be a future management approach.

- *Areas of high Ribes density should be avoided, since this is the alternate host of the fungus.* However, *Ribes* plants were observed in all stands sampled in this study. Only the spores that come from *Ribes* plants infect pines. These spores are highly susceptible to drying and ultraviolet radiation from the sun. Therefore, the spores that infect pines do not travel long distances, and do not survive for long periods after being released from *Ribes*. Removing *Ribes* plants within a stand and immediately around a stand has been proven effective at controlling white pine blister rust in the Lake States, but the methods have never been tested in the Rocky Mountain Region.

- *Establishing pine regeneration under an existing overstory is an effective control for the rust for eastern white pine.* The overstory reduces moisture formation on needles, which is necessary for rust infections to occur. Around 40-50 percent crown closure of the overstory has been recommended. When trees are about 20 ft tall, the pines are released by removing the overstory. However, limber pine is less shade tolerant that eastern white pine.

Management strategies for mountain pine beetle. Several methods are available to reduce populations of mountain pine beetle and associated tree mortality. These pest management strategies focus on the reduction of infested material, reduction of susceptible host material, and/or prevention of new attacks. Important strategies for mountain pine beetle management are recognition of the problem and reducing susceptible stand conditions that might lead to epidemics. The best way to deal with epidemics is not to allow them to get large.

Thinning stands might increase tree resistance. For ponderosa and lodgepole pines, reducing stand densities to 60-80 square ft per acre of basal area reduces susceptibility to bark beetle attack. Reconstruction of a 1930s mountain pine beetle epidemic in whitebark pine (*Pinus albicaulis* Engelm.), determined that all stands above 44 square ft per acre or with a stand density index greater than 80 were attacked (Perkins and Roberts 2003). However, the relationship between stand structure and beetle-caused mortality has not been investigated in limber pine and stand density information is not available.

Sanitation in stands. Combined with thinning, a good tactic for managing mountain pine beetle where they currently threaten limber pine is sanitation. Removing infested green trees from a stand prior to the emergence of adult beetles in late July and early August reduces further spread. This action removes the developing beetle population in localized areas of stands. Removing trees after adult beetles emerge will not affect beetle populations. If infested trees cannot be removed, sanitation can be achieved by destroying the beetle brood within their host tree. Currently infested trees can be felled and treated by burning, chipping, peeling the bark, exposing logs to the sun, or drenching with an appropriately registered insecticide prior to beetle emergence. This treatment is effective in areas adjacent to more heavily infested stands, and for small infestations. Combining sanitation with other pest management treatments can improve control of the beetle.

Insecticides and pheromones. Protecting trees from attacks using insecticides and pheromones has already been described under management strategies for white pine blister rust. Due to costs, this strategy should be reserved for high value trees.

Management of dwarf mistletoe. The removal of dwarf mistletoe before it spreads is the best method for managing the problem in the small, yet heavily infested area of the Bighorn National Forest. This would involve the removal of all infested trees in the area, and/or pruning of all infested branches. Dwarf mistletoe cannot live outside host tissue, so removing infected tissue eliminates the disease.

LITERATURE CITED

Brown, D. H., and Graham, D. A. 1969. White pine blister rust survey in Wyoming, Idaho, and Utah: 1967. State and Private For. Rpt., USDA For. Serv., Northern Region.

Johnson, E., and Long, D. F. 2001. 2000 Forest Health Management aerial survey. FHM Rpt. 3410, RCSC_01_2, USDA For. Serv., For. Health Mgt., Rocky Mountain Region.

Kegley, S., and Gibson, K. 2004. Protecting whitebark pine trees from mountain pine beetle attack using verbenone. FHP Rpt. 04-8, USDA For. Serv., For. Health Protection, Northern Region.

Perkins, D. L., and Roberts, D. W. 2003. Predictive models of whitebark pine mortality from mountain pine beetle. For. Ecol. Manage. 495-510.

Schwandt, J., and Kegley, S. 2004. Mountain pine beetle, blister rust, and their interaction on whitebark pine at Trout Lake and Fisher Peak in northern Idaho from 2001-2003. FHP Rpt. 04-9, USDA For. Serv., For. Health Protection, Northern Region.

Van Arsdel, E. 1961. Growing white pine in the Lake States to avoid blister rust. Tech. Rpt. 92, USDA For. Serv., Lake States For. Exp. Stn.

APPENDIX 1

Results summarized in tables by stand.

Table 1. Site descriptions for each stand in the Bighorn National Forest in 2002.

Stand	Northing[1] (utm)	Easting[1] (utm)	Elevation (ft)	Topography	Stand Structure	Slope (degree)	Aspect	Mean DBH[2] of Limber pine (in)	Mean DBH[2] of all species (in)	*Ribes*[3] Incidence (%)	*Ribes*[4] Abundance (0-2)
1	4985333	285489	6,916	Convex slope	Even-aged	12	North	6.2	6.3	100	2.0
2[5]	4939168	296714	7,693	Ridge top	Mosaic	13	North/South	7.0	6.3	50	1.0
3	4983699	281956	8,460	Even bench/slope	Even-aged	18	South	7.8	8.0	33	0.5
4	4950811	281968	8,290	Even bench/slope	Two-storied	14	South	9.6	9.9	83	1.3
5	4887714	319140	7,287	Even bench/slope	Uneven-aged	17	East	5.0	5.0	17	0.2
6	4891590	322146	9,293	Ridge top	Uneven-aged	7	South	7.4	7.8	50	0.7
7	4975173	282127	8,790	Ridge top	Even-aged	13	West	7.1	6.9	100	1.5
8[5]	4963258	312844	7,446	Concave slope	Mosaic	17	West	7.7	7.7	75	1.5
9	4967141	290434	8,777	Ridge top	Uneven-aged	11	West	6.9	6.6	50	0.8
10	4932896	301043	9,010	Ridge top	Even-aged	15	South	10.8	10.3	100	2.0
11	4942520	333776	7,127	Ridge top	Even-aged	9	North/South	6.8	6.8	50	0.7
12	4923159	304800	8,803	Even bench/slope	Even-aged	23	East	8.7	9.5	100	1.8
13	4934114	300583	8,775	Even bench/slope	Even-aged	23	East	9.9	10.2	67	1.0
14	4964051	295621	8,249	Convex slope	Uneven-aged	15	South	8.6	8.6	33	0.5
15	4943819	330785	7,659	Ridge top	Uneven-aged	17	South	7.9	7.9	100	1.2
16	4904543	314298	9,174	Even bench/slope	Uneven-aged	17	West	7.0	6.9	100	1.5

[1] UTM units in zone 13; datum NAD 27.

[2] Diameter at 4.5 ft.

[3] Mean percentage of plots in which *Ribes* spp. were present in stands.

[4] Mean score of *Ribes* spp. abundance where: 0 = *Ribies* not detected; 1 = less than 200 *Ribes* plants per acre; 2 = greater than 200 *Ribes* plants per acre in stands.

[5] Stands 2 and 8 had only 4 plots, all other stands had 6 plots.

Table 2. Mean percent of stems among plots per stand for individual tree species and total number of stems for all trees in each stand in the Bighorn National Forest in 2002.

	Mean percent of stems per plot						
Stand	Limber pine (%)	Douglas-fir (%)	Engelmann spruce (%)	Lodgepole pine (%)	Rocky Mtn juniper (%)	Other species[1] (%)	Number of stems per acre
1	97	3	0	0	0	0	443
2	62	10	0	0	26	2	120
3	69	15	14	0	0	2	333
4	80	19	2	0	0	0	158
5	16	4	0	0	72	8	185
6	90	7	3	0	0	0	500
7	66	5	21	0	0	8	670
8	81	0	0	19	0	0	275
9	74	0	22	4	0	0	380
10	81	0	19	0	0	0	397
11	100	0	0	0	0	0	350
12	74	25	2	0	0	0	340
13	91	9	0	0	0	0	233
14	91	0	0	9	0	0	200
15	100	0	0	0	0	0	233
16	76	0	23	0	0	2	270

[1] All other species, including: ponderosa pine, hardwood species, and unidentified species.

Table 3. Mean percent basal area among plots per stand for individual tree species and basal area of plots for all trees in each stand in the Bighorn National Forest in 2002.

	Mean percent basal area per plot						
Stand	Limber pine (%)	Douglas-fir (%)	Engelmann spruce (%)	Lodgepole pine (%)	Rocky Mtn juniper (%)	Other species[1] (%)	Basal area (ft^2/acre)
1	97	3	0	0	0	0	89.8
2	76	12	0	0	11	1	28.8
3	64	20	15	0	0	1	122.4
4	77	23	< 1	0	0	0	101.2
5	29	12	0	0	47	13	31.7
6	81	16	3	0	0	0	179.3
7	67	6	23	0	0	4	204.7
8	81	0	0	19	0	0	63.9
9	77	0	19	4	0	0	103.7
10	85	0	15	0	0	0	283.6
11	100	0	0	0	0	0	94.4
12	65	32	3	0	0	0	184.0
13	86	14	0	0	0	0	148.7
14	91	0	0	9	0	0	93.6
15	100	0	0	0	0	0	85.9
16	68	0	27	0	0	5	92.8

[1] All other species, including: ponderosa pine, hardwood species, and unidentified species.

Table 4. Summary of health and mortality agents observed on limber pine for each stand in the Bighorn National Forest in 2002.

				Mortality agents					
Stand	All Limber pine[1] (stems/acre)	Dead Limber pine[2] (%)	Crown health[3] Live crown (%)	Branch canker[4] Severity (0-3)	Branch canker[5] Incidence (%)	Stem canker[6] Incidence (%)	Dwarf mistletoe[7] Incidence (%)	Mtn pine beetle[8] Incidence (%)	Fire[9] Incidence (%)
1	547	22	71	0.6	40	24	0	0	1
2	75	0	96	0.6	45	6	0	0	0
3	290	16	79	0.1	8	1	0	0	11
4	135	1	94	0.4	40	3	0	16 (16)	0
5	77	43	28	2.3	100	77	0	80 (40)	0
6	483	5	92	0.5	50	9	0	7 (0)	0
7	483	10	89	0.1	10	1	0	0	0
8	118	3	78	1.6	83	32	0	0	0
9	275	1	99	0.1	9	1	0	0	0
10	340	2	94	0.6	51	8	0	3 (3)	0
11	540	35	55	2.1	94	65	0	1 (1)	0
12	287	6	88	0.1	15	0	0	20 (20)	0
13	217	1	99	0.2	17	2	0	8 (8)	0
14	183	2	98	0.2	16	3	0	0	0
15	287	18	64	1.9	90	65	17	0	0
16	210	0	98	0.6	46	13	0	0	0

[1] Number of limber pine stems per acre, including dead trees.
[2] Mean percentage of dead limber pine per plot within stands.
[3] Mean percentage of living crown per tree within stands.
[4] Mean rank of branch cankers per tree within stands where: 0 = no branch cankers; 1 = 1-3 branch cankers per tree; 2 = 4-9 branch cankers per tree; 3 = more than 10 branch canker per tree.
[5] Mean incidences of branch cankers on trees within stands.
[6] Mean incidences of stem cankers on trees within stands.
[7] Mean incidence of dwarf mistletoe on trees within stands.
[8] Mean incidence of mountain pine beetle for the last 2 years in trees within stands, with 2002 mountain pine beetle attacks in brackets.
[9] Mean incidence of fire mortality of trees within stands.

Table 5. Summary of other observations of limber pine for each stand in the Bighorn National Forest in 2002.

Stand	*Dendroctonus valens*[1] (%)	*Ips* spp.[2] (%)	Other insects[3] (%)	Physical damage[4] (%)	Lightning damage[5] (%)
1	0	2	1	2	0
2	0	0	0	9	0
3	0	2	3	3	1
4	0	0	0	22	0
5	8	2	6	2	0
6	0	0	0	4	1
7	0	0	0	1	0
8	0	0	0	0	0
9	0	0	0	7	0
10	0	0	0	8	0
11	0	1	1	8	0
12	1	2	0	4	0
13	0	0	0	5	0
14	0	0	0	3	0
15	0	1	0	3	0
16	0	0	0	0	0

[1] Mean incidence of *Dendroctonus valens* in trees.

[2] Mean incidence of *Ips* spp. in trees.

[3] Mean incidences of other insects including pitch moth and carpenter ants in trees.

[4] Mean incidence of mechanical damage including wind to trees.

[5] Mean incidence of Lightning damage to trees.

APPENDIX 2

Analytical summary including relationships among various ecological variables.

Table 1. Correlations among variables for plots in the Bighorn National Forest in 2002.

Variables	Correlation coefficient	*P*-value[a]
Branch canker incidence[b] and:		
branch canker severity[c]	0.926	< 0.001
stem canker incidence[d]	0.810	< 0.001
stem canker severity[e]	0.800	< 0.001
Crown health[f] and:		
branch canker incidence[b]	-0.558	< 0.001
branch canker severity[c]	-0.717	< 0.001
stem canker incidence[d]	-0.789	< 0.001
stem canker severity[e]	-0.708	< 0.001
Branch canker incidence[b] and:		
northing[g]	-0.403	< 0.001
easting[g]	0.709	< 0.001
elevation	-0.541	< 0.001
number of dead limber pine	0.218	0.037
Stem canker incidence[d] and:		
northing[g]	-0.283	0.006
easting[g]	0.671	< 0.001
elevation	-0.655	< 0.001
mean DBH of limber pine	-0.385	< 0.001
number of dead limber pine	0.361	< 0.001
basal area of limber pine	-0.316	0.002

[a] Probabilities are based on simple linear regression; $N = 92$.
[b] Mean incidences of branch cankers on trees within plots.
[c] Mean rank of branch cankers per tree within plots where: 0 = no branch cankers; 1 = 1-3 branch cankers per tree; 2 = 4-9 branch cankers per tree; 3 = more than 10 branch canker per tree.
[d] Mean incidences of stem cankers on trees within plots.
[e] Mean rank of stem cankers per tree within plots where: 0 = no stem cankers; 1 = 1 stem canker per tree; 2 = 2 or more stem cankers per tree.
[f] Mean percentage of living crown per tree within plots.
[g] UTM units in zone 13; datum NAD 27.

Notes:

- Branch canker incidence has a strong correlation with branch canker severity, stem canker incidence, and stem canker severity. This indicates that any of these observations can be used to describe white pine blister rust frequencies within plots, and that frequency and severity of white pine blister rust on limber pine in the Bighorn National Forest have a strong linear relationship.

- Crown health was well correlated with both branch and stem canker incidence and severity, suggesting that much of the observed crown deterioration in the Bighorn National Forest is due to white pine blister rust.

- In the Bighorn National Forest, white pine blister rust branch canker incidence increases to the south, east, and as elevation decreases.

Table 2. Correlations between mountain pine beetle incidence and various variables, for stands in which mountain pine beetle was present, in the Bighorn National Forest in 2002.

Variables	Correlation coefficient	*P*-value[a]
Mountain pine beetle incidence[b] and:		
elevation	-0.379	0.013
crown health[c]	-0.704	< 0.001
branch canker severity[d]	0.434	0.004
branch canker incidence[e]	0.296	0.057
stem canker incidence[f]	0.505	0.001

[a] Probabilities are based on simple linear regression; $N = 42$.
[b] Mean incidence of mountain pine beetle for the last 2 years in trees within plots.
[c] Mean percentage of living crown per tree within plots.
[d] Mean rank of branch cankers per tree within plots where: 0 = no branch cankers; 1 = 1-3 branch cankers per tree; 2 = 4-10 branch cankers per tree; 3 = 11 or more branch canker per tree.
[e] Mean incidences of branch cankers on trees within plots.
[f] Mean incidences of stem cankers on trees within plots.

Notes:

- In the Bighorn National Forest, mountain pine beetle incidence increases as elevation decreases.

- Crown health was well correlated with mountain pine beetle incidence, suggesting that much of the observed crown deterioration in the Bighorn National Forest can be attributed to the beetle, for stands in which mountain pine beetle occurred.

- Mountain pine beetle incidence was positively correlated with branch canker severity and stem canker incidence, indicating a possible additive effect. It is probable that white pine blister rust is weakening the trees making the trees more susceptible to mountain pine beetle attack.

Table 3. Standard errors of branch canker incidence for plots within each stands and for all plots in the Bighorn National Forest in 2002.

Stand	*N*	Standard error
1	6	3.29
2	4	15.0
3	6	5.17
4	6	9.76
5	6	0.00 [a]
6	6	8.39
7	6	3.53
8	4	6.01
9	6	4.26
10	6	4.45
11	6	2.18
12	6	11.7
13	6	6.28
14	6	6.57
15	6	6.25
16	6	7.15
Overall	92	3.62

[a] Every limber pine in stand 5 had at least one branch canker, therefore the branch canker incidence for every plot was 100%.

Note:

- Twelve of the 16 stands had standard errors of branch canker incidence greater than the overall standard error for the study. This shows that there is much within stand variation. Therefore, multiple plots are needed to describe stand variations.

Table 4. Relationships between topography and branch canker incidence and mountain pine beetle incidence for plots in the Bighorn National Forest in 2002.

	Topography[a]				
Variables	**2**	**3**	**4**	**5**	***P*-value**[b]
Branch canker incidence[c]	83 c[d]	38 ab	28 a	50 b	0.016
N =	4	36	12	40	
Mountain pine beetle incidence[e]	-	31 b	-	4 a	0.007
N =	0	24	0	18	

[a] Topography categories include: 2 = concave slope; 3 = even bench or even slope; 4 = convex slope; 5 = ridge top.
[b] Probabilities are based on analysis of variance.
[c] Mean incidences of branch cankers on trees within plots.
[d] Values in a row followed by different letters are significantly different ($P = 0.05$) based on Fisher's LSD.
[e] Mean incidence of mountain pine beetle for the last 2 years in trees within plots.

Notes:
- Results suggest that topography might influence branch canker incidence and mountain pine beetle incidence. However, this survey was not designed to fully explore those relationships.

Table 5. Relationships between stand structure and branch canker incidence and mountain pine beetle incidence for plots in the Bighorn National Forest in 2002.

	Stand structure[a]				
Variables	**1**	**2**	**3**	**4**	***P*-value**[b]
Branch canker incidence[c]	33 a[d]	40 a	52 ab	64 b	0.034
N =	42	6	36	8	
Mountain pine beetle incidence[e]	8 a	16 a	44 b	-	0.007
N =	24	6	12	0	

[a] Stand structures includes: 1 = even-aged; 2 = two-storied; 3 = uneven-aged; 4 = mosaic.
[b] Probabilities are based on analysis of variance.
[c] Mean incidences of branch cankers on trees within plots.
[d] Values in a row followed by different letters are significantly different ($P = 0.05$) based on Fisher's LSD.
[e] Mean incidence of mountain pine beetle for the last 2 years in trees within plots.

Notes:
- Results suggest that stand structure might influence branch canker incidence and mountain pine beetle incidence. However, this survey was not designed to fully explore those relationships.

Correlations that were not statistically significant.

Notes:
Variables that were not significantly correlated with incidence of white pine blister rust branch cankers include: *Ribes* incidence and abundance, slope, aspect, mean DBH of limber pine, number of limber pine stems, percentage of limber pine stems, basal area of limber pine, percentage basal area of limber pine, and incidence of dwarf mistletoe, fire, *Dendroctonus valens*, *Ips* spp., other insects, physical damage, or Lightning damage.

Variables that were not significantly correlated with incidence of white pine blister rust stem cankers include: *Ribes* incidence and abundance, slope, aspect, number of limber pine stems, percentage of limber pine stems, percentage basal area of limber pine, and incidence of dwarf mistletoe, fire, *Dendroctonus valens*, *Ips* spp., other insects, physical damage, or Lightning damage.

Variables that were not significantly correlated with incidence of mountain pine beetle include: *Ribes* incidence and abundance, slope, mean DBH of limber pine, number of dead limber pine, and incidence of dwarf mistletoe, fire, *Dendroctonus valens*, *Ips* spp., other insects, physical damage, or Lightning damage.